Assessing the effectiveness of a flipped classroom in foundational engineering dynamics

Report

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A flipped classroom approach has been touted as a future teaching methodology in the Department of Mechanical Engineering at the University of Canterbury. A pilot implementation of the approach was trialled in a small cohort of first year engineering students. This research assessed the efficacy of the approach.

Qualitative and quantitative methodologies were used to determine the effectiveness of the approach. The quantitative approach used a researcher independent metric of academic success. Semi-structured interviews were used to gather student impressions of the approach. The quantitative approach showed that the student performance was not significantly changed by the flipped approach. However, the qualitative analysis showed that the approach was appreciated by the students. In particular, the student's liked the collaborative environment of the help sessions, and the increased direct communication with the lecturer, as well as the flexibility that independent learning provided to them.

The expansion of the approach within the mechanical engineering undergraduate teaching is feasible. The implementation of the approach was not particularly arduous and the overall student experience was enhanced by the approach.

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1. Introduction

The efficacy of the flipped classroom approach for teaching engineering in a New Zealand tertiary environment was assessed in a mixed methods study. An early formalisation of the approach was published in 1982 (Baker, 2000) but has become popular in recent times due to availability of technology, malleability of teaching methodologies, and fiscal restrictions and pressures, pressures on time and resources within universities, and an increased student demand for student-centred teaching. The flipped classroom approach has the potential to provide educators with an opportunity to fulfil these varied influences on modern practice. However, it is important to directly access the applicability and efficacy of the methodology within the proposed contexts it may be expanded to cater for. Hence, student feedback, impressions, and achievement must be considered.

This study investigated engineering students' impressions of the flipped classroom approach and their ongoing academic achievement in follow-on courses. The approach was utilised to teach a summer school paper to two separate cohorts over two consecutive years. The course content covered foundational engineering dynamics and was in the first year of a four year Bachelor of Engineering (with honours) degree programme in New Zealand.

1.1. Motivation for the Study

Recently, the tertiary teaching sector has had an increased uptake of alternative methods of teaching and learning (Blair et al., 2016). There is some literature reporting success and failure of the flipped classroom approach (Blair et al., 2016, Love et al., 2014, Lavelle et al., 2013, Gannod et al., 2008). In an effort to assess whether the flipped classroom is beneficial or detrimental for engineering students, a flipped classroom approach was trailed in two summer school cohorts over a period of two years. This study gathered the student impressions and ongoing academic success as well as recorded suggestions for making further improvements to the course and wider implementation of the methodology.

Students are increasingly expecting self-paced learning within the tertiary sector. The readiness of information allows students to quickly compare and contrast educational institution practices. Thus, in order to remain competitive, institutions must adapt and uptake the most well-accepted and successful teaching methodologies. There is also increased pressure from qualification authorities and governments for universities and other tertiary institutions to perform more effectively and efficiently (Bishop and Verleger, 2013, O'Flaherty and Phillips, 2015b).

1.2. Literature Review

1.2.1. The Flipped Classroom Defined

The flipped classroom approach uses two distinct stages: **(1)** course content introduction and delivery at the students' own time and pace (often delivered online). Course content is presented as readings, videos, graphical presentations or quizzes (Lavelle et al., 2013, Blair et al., 2016, Hanson, 2016). Students engage with this material at their own time and pace. **(2)** These 'lectures' are followed with workshops within which students engage with the recently delivered course materials (Bishop and Verleger, 2013). The workshop sessions often include elements of interactive, collaborative and applicative engagement with the

course content and solidify the concepts delivered by the materials (Lavelle et al., 2013, Bishop and Verleger, 2013, Hanson, 2016).

1.2.2. *Rationale for and Characteristics of Flipped Classroom in Tertiary Education*

Blair et al. (2016) suggest that recent technological advances facilitated the shift in tertiary teaching from the traditional teacher-centred approach to a student-centred approach. Mayer (2002) notes that the approach facilitates knowledge uptake and retention as opposed to simple transfer of knowledge and facts. The shift to student-centred pedagogy resonates with the sociocultural learning theory of Vygotsky (1978). In particular, the 'Zone of Proximal Development', is directly relevant to student learning within the flipped classroom. Sociocultural approaches to education contrast with traditional approaches that suggest the students' learning unfolds via orderly stages. In contrast, the sociocultural theory focuses on the roles teachers and peers play in education with an emphasis on group interactions and collaborative learning (Richardson, 1998, Daniels, 1996).

Guided participation has been recognised as essential to uptake of thought patterns that are consistent with individuals that are proficient in particular fields (Bishop and Verleger, 2013). This important learning methodology is intrinsic within the flipped classroom approach as learning occurs both collaboratively and independently (Lavelle et al., 2013). In particular, while students engage with course content independently, scheduled class times enable guided participation via collaboration and direct lecturer engagement. Sociocultural conflict theory is thus particularly relevant to the flipped classroom approach to learning. This theory suggests that theoretical discrepancy or conflict across individuals sparks cognitive development. Furthermore, socio-cognitive conflict theory recognises conflict as essential to cognitive change. Doise and Mugny (1984) demonstrated that students working in pairs solve higher level problems than those working in isolation; regardless of their partner's ability. When students were challenged with alternative opinions, their own performance was enhanced, regardless of the validity of the opposing points-of-view; thus, the social interaction of working in partnership enhanced and augmented the learning and performance of the students.

Engineering inherently requires real-world skills that must be taught (Choi, 2013). The flipped classroom has exhibited positive outcomes in lab-based classes (Lavelle et al., 2013). The increased direct student-teacher engagement ultimately facilitates better mentoring of practical skills. The mentoring occurs as required and is thus relatively efficient (Lavelle et al., 2013).

Johnson and Renner (2012), Lavelle et al. (2013), and Blair et al. (2016) identify a number of advantages for the flipped classroom. Course materials can be altered to provide for a diverse range of students with differing learning styles and can also be adapted to suit those with disabilities. Formative assessment can be utilised to provide ongoing support and feedback to students, in a way that fits with the natural flow of the help sessions. In contrast, such practice in traditional lectures is not well-received by students. Choi (2013) argues that the flipped classroom promotes specific and immediate feedback for optimal education settings.

Barker (2000) noted the shift of the teacher to a 'facilitator' rather than a 'director' of learning in the flipped classroom. This was coupled with concurrent increases in: direct

communication between the teacher and students, use of active learning, focus on understanding and application, provision of student control, a greater sense of student responsibility over learning, and collaboration.

The flipped classroom approach has some intrinsic disadvantages. Notably, Johnson and Renner (2012) suggest that students must be disciplined to succeed in a flipped classroom. Furthermore, the approach assumes that students have internet access. Some students are not inclined to view the materials prior to their workshop classes and thus the collaborative environment can become ineffective. Also, material development and editing is generally very labour intensive (Lavelle et al., 2013).

1.2.3. Students' Perceptions of the Flipped Approach to Learning

Student perception of the flipped classroom varied broadly (Johnson and Renner, 2012, Blair et al., 2016, Love et al., 2014, Nguyen et al., 2015, Hanson, 2016). Blair and Colleagues (2016) report that after engineering students engaged in a flipped classroom they were keen for a wider deployment of the methodology. Student perceptions of the approach were heavily influenced by the online material quality (Blair et al., 2016). Hanson (2016) noted that increased understanding through dialogue in the face-to-face component, wider and deeper thinking, the ability to pause and replay the online lecture material and the flexibility of time to avoid conflicting commitments and students also acknowledged a reduced sense of isolation and disengagement were all benefits of the approach. A number of students indicated that the flipped classroom requires different pedagogical approaches to ensure sustained academic performance and recognised the overall approach requires self-discipline from the students. Somewhat unexpectedly, students also recognised that the flipped approach was more efficient than the traditional lecture approach (Blair et al., 2016, Nguyen et al., 2015, Hanson, 2016, O'Flaherty and Phillips, 2015b).

Nguyen et al. (2015) noted student feedback that communicating with fellow students while watching online lecture materials was beneficial and an important aspect of good pedagogy. They also recognised that engagement with the recorded online material was critical to success (Nguyen et al., 2015, Pierce and Fox, 2012, Blair et al., 2016). Students in several studies noted the reviewability of the materials as a significant positive for the flipped classroom (Pierce and Fox, 2012, Love et al., 2014, Blair et al., 2016).

Hanson (2016) reported that there lacked uniform positivity for the approach. In particular, some students felt unprepared for the approach. O'Flaherty and Philips (2015b) found similar responses where students were initially ambivalent to the need to engage in both workshops and the online materials. Nguyen (2015) and Zhu et al. (2016) suggest that students must be informed of the value of discipline when engaging with flipped education.

The literature indicates varied academic achievements from students of the flipped classroom. O'Flaherty and Phillips (2015) reviewed a number studies and found that, in general, there was an improvement in students' academic achievement concurrent with the use of flipped approaches. In studies typically measured either with pre vs post test scores or course grades compared to those of previous years where traditional approaches were used. However, both metrics are highly investigator dependent, and thus, the statistical validity of the outcomes is tenuous. Kerr confirmed that there is some improvement in engineering students' academic achievement when flipped approaches are being used (Kerr, 2015). Yelamanthi and Drake compared the achievement of 17 students who

participated in a flipped version of a first year Digital circuits course to 22 students participating in the traditional version of the same course and found a significant improvement in students' academic success from students of the flipped classroom (Yelamanthi and Drake, 2015). However, the ability of the lecturer to provide individualised assistance to students of the small class limits the applicability of the outcomes to larger cohorts. Wilson compared student results across a flipped cohort and a previous years' traditional class cohort in an engineering management course (Wilson, 2013) and found a lack of statistically significant differences in student achievement across methodologies. This is despite a clear indication that students preferred the flipped approach. Similarly, Mason, Shuman and Cook, in their study of flipped approaches in a senior year Control Systems course, found that students in the flipped classroom only performed better than students in the traditional classroom when solving certain problems (Mason et al., 2013). The authors conclude that the flipped approach "at best improved students' understanding of engineering concepts, and at worst did no harm". Statistically, this metric and interpretation is invalid and unfounded, as if one measures enough outcomes, one may expect significant outcomes in some cases as a matter of statistical likelihood. This is an example of 'p-hacking' (Selvin and Stuart, 1966).

Most importantly, it is a reasonable assumption that publication bias obscures the true impact of the flipped classroom on the academic success of students (Pigott et al., 2013, van Hilten, 2015, Dickersin, 1990). In particular, publication bias can occur when studies that had negative or ambiguous outcomes due to the intervention decide not to publish their findings. This loads the academic literature with a biased collection of outcomes and recommendations. Pigott et al. (2013) assessed a number of educational intervention thesis to their published versions and found that statistically significant outcomes were more likely to be published than non-significant outcomes. The authors urge researchers to report all findings in order to generate a more even body of academic literature in educational interventions. Such a culture change will lead to successful and representative meta-analysis of outcomes, and thus data driven policy change can be undertaken without fear that the data is affected by bias or statistical anomalies.

2. Study design

This study utilised a mixed method methodology to capture the qualitative and quantitative outcomes of student achievement and impressions of the flipped classroom approach. The class analysed was a mechanics class that is foundational in the degree structures of civil and mechanical engineering at the University of Canterbury. The flipped classroom was restricted to only the second half of the course that concentrated on engineering dynamics.

2.1. Overview of Degree Structure

Engineering at the University of Canterbury uses a structure with two semesters of four papers in each. A bachelor of engineering with honours degree (BE (hons)) has 32 papers and is a four year program (assuming a full course load). All classes are compulsory and students are required to repeat classes if they fail them. The first-year (termed the 'intermediate year') includes foundational engineering and physical science content. The following years are labelled the first, second and third professional years. The professional years prepare the students to practice as professional engineers. Entrance to the first professional year of engineering is competitive. Student intermediate year grades are the basis for comparative entry to their preferred engineering disciplines. International exchange students are sometimes allowed to enrol in selected courses within the program as well.

2.2. Course Content First-year Mechanics Course

The statics section of the first-year mechanics course taught analysis of rigid body forces, distributed forces, trusses, and three dimensional vector operations. The dynamics section taught simple kinematic, equations of motion via Newton's Laws, work, impact, collisions and energy methods.

2.2.1. Semester 2 - Traditional Delivery

The traditional delivery of the course involved 48 lectures that had a 50 minute duration. The first twenty four lectures delivered the statics content and final 24 lectures delivered the dynamics section. There were four lectures and one two-hour tutorial per week and a two-week break between the statics and dynamics sections. Online quizzes provided formative assessment and there were three graded labs. There was a statics test in the first week of the dynamics section and an exam approximately two weeks after the dynamics section.

The dynamics lecturer annotated prepared notes under a document camera with occasional physical demonstration. The students had access to the unannotated notes and copied annotations while the lecturer verbally described the content.

2.2.2. Summer semester – Partial Flipped Delivery

There were a total of 24 lectures that were 110 minutes in duration. There were three lectures per week and the course was divided into two four-week blocks either side of a two-week Christmas break. Hence, the delivery rate of taught materials was faster in the summer occurrence of the course than the semester 2 occurrence. This increased pace was deemed acceptable as students were limited to enrolling in only two summer papers. Only the dynamics section of the summer occurrence was taught using the flipped delivery. In contrast, the statics teaching used the traditional lecture model.

The flipped environment provided the students with video lectures that were prepared in a PowerPoint framework. The videos used the same notes as the traditional delivery and similar annotation would appear in the videos as the lecturer orally described the content. A 50 minute lecture would typically condense to a ~35 minute video. The students watched two video lectures before attending each scheduled workshop. Students generally annotated their notes mimicking the annotations of the videos and brought their annotated notes to the scheduled workshop. Scheduled workshops started with question/answer sessions. However, since students can resist in-class participation (Magnuson-Martinson, 1995, Eble and McKeachie, 1985, Hollander, 2002), the lecturer encouraged a culture of participation by planting questions before the first session. The lecturer also required students to work on problems in groups. The question and answer part of the face to face session generally lasted 30-40 minutes, depending on the issues that arose. The remainder of the session was dedicated to example problems that required the content presented in the previous lectures to complete the problems. Opportunities for student feedback (online and face to face) were also frequently provided, in order to inform the lecturer's approach with the flipped classroom and to identify possible challenges that the students needed further support on.

3.   Qualitative Methodology

Qualitative methods were used to evaluate the students' perceptions and impressions of the flipped classroom methodology. Interpretivism is the study of why social action occurs by first understanding how emotions and world views motivate individuals (Neuman, 2000). The aim of the interpretive paradigm is to understand the subjective individual experiences with the integrity of the subject. The paradigm also aims to understand how people construct meaning from their environment (Neuman, 2000, Taylor and Bogdan, 1998). The interpretivist paradigm enabled the researchers to examine student perspectives on the flipped classroom, their interaction with their lecturer, the technologies used, and other culturally situated tools were used to construct engineering dynamics knowledge and understanding.

Twenty students in the flipped classroom participated in semi-structured, focus-group interviews. Students were recruited via emails that were addressed to the 2014 and 2015 summer cohorts. Students were offered $50 to $100 remuneration to cover costs of attending the interviews and to encourage participation. In total eight interviews were undertaken and scheduling limitations required two individual interviews.

Interviews were undertaken by either Dr Fox-Turnbull or Ms Zaka. External agencies were used to transcribe recorded interview audio. Aspects of this research were ethically restrictive (Cohen et al., 2013) as Dr Docherty was the course lecturer and had ongoing authority over the students. In particular, he had roles that involved grading and pastoral support. Due to these ethical considerations, Dr Docherty did not undertake any of the interviews, and received anonymised interview transcripts.

Semi-structured interviews explore peoples' motivations and actions (Taylor and Bogdan, 1998). Focus groups can yield insight not otherwise accessible in structured interviews as the participants can be prompted by the contributions of others (Cohen et al., 2001). However, focus group interviews must be interpreted in terms of the group dynamics and the impact of other participants on individual responses (Taylor and Bogdan, 1998). Interview transcripts interviews were coded and analysed to identify several key factors that influenced students' experiences and perspectives of the flipped classroom approach.

3.1.   Qualitative Findings

Students were predominantly positive towards the flipped classroom experience. However, one student was notably negative. The outcomes showed that student perceptions fell into two broad categories **(1)** teaching and **(2)** learning. Each category exhibited a number of themes which are summarized below. Factors, such as student responsibility for time management, or working collaboratively were perceived as both positively and negatively.

Perspectives of Teaching

•   Course Materials

•   The Process

•   Lecturer Approach

•   Preparation of Student

Perspectives of Learning

•   Reviewability

•   Independence

•   Time Management

•   Working Collaboratively

3.1.1. Students' Perspectives of Teaching

Some students noted that course materials were easily accessed via the designated Online Learning Environment (based on the Moodle platform) and fitted well into their schedules. However, nearly all students experienced frustration due to errors in the video material. Students accepted that mistakes would be time consuming to fix; while others offered a solution:

> *"Have you guys watched The Khan Academy? so… [the lecturer] was complaining that if he has an error in his recordings then he has to start from scratch. He was having editing issues, but what Sal [in the Khan videos] does he just puts a little text box at the bottom and says, hey look, this is wrong and this is what I meant to say. It would have reduced the time and effort that we spend quite dramatically" (Student D).*

There was also a recommendation that the videos should be developed by people who specialise in video production.

Students felt empowered by the emphasis on problem solving in workshops. Many students would have preferred earlier access to lecture material. Similarly, the worked examples to be undertaken in workshops were requested in advance: *"Maybe write a list of questions out and then you know what you will ask at the next tutorial. Just keeping up-to-date"* (Student N). However, the lecturer noted that providing such examples in advance would provide little benefit to the students. In particular, there are many examples in the video lectures that students could engage with prior to the flipped classroom, and providing examples prior to the worked session would mitigate the lecturer's ability to contribute to student learning in real-time. Others mentioned that they would prefer a variety of materials for asynchronous learning. One student suggested that an additional online could improve peer-to-peer learning. Furthermore, some students experienced frustration with duration of the videos and

the time taken to watch *"for me it was at least three hours in the evening after I came home from work…you finish that and you are exhausted"* [Student A].

Most students indicated that they experienced increased engagement in the course due to the flipped approach.

> *"When you're taking notes in real time lectures you focus more on taking notes and you don't have time to digest the information and they find it quite useful; that [in the flipped classroom] they could pause and think about what they just wrote and the content sunk in better"* (Student O).

Over half of the students mentioned that they like the frequency of the tutorials, which were held three times a week over the four week section of the course. A number of students mentioned the approach forced their engagement in the course. Most students considered the increased engagement a positive aspect of the approach; *"compared to my first year grade I was normally [understanding course content] on a higher level so yeah I was more engaged, I was willing to work harder"* (Student F). Another student suggested that while the course took more time than the traditional approach, she knew the material better and therefore required less effort to prepare for the end of year examination. Perhaps surprisingly, it was only a minority of students that mentioned the increased time commitment of the approach as a negative. Some noted that using the flipped approach for more than one course per semester would be challenging.

Three students noted improved academic achievement due to the approach: *"I'd say just that the teacher and the way he taught was very effective and reflected in my results"* (Student L). Nearly all students were positive about the collaborative nature of the workshops which provided unique opportunities to interact with the lecturer on a one-to-one basis. They noted that the small class sizes and the resulting group dynamics, *"We were sitting in groups and the girls in my group really helped me out"* (Student F), *"you kind of need someone who learns with you"* (Student F).

Students in the study were very positive about the lecturers approach during the course and noted the increased engagement during the flipped classroom; *"I'd say just the teacher and the way he taught it was very effective, and that reflected in my results"* (Student L). Students valued the direct engagement with the lecturer during the workshop sessions: *"[It was] easier to get that one-on-one time, easier to get the help you needed"* (Student M). Two students specifically noted their appreciation for the lecturer's time investment in making the videos. Some students suggested that the lecturer utilise both his own material and other readily available resources. In particular, the Khan Academy was mentioned several times: *"Lecturers tend not to use that resource [internet], they don't give you links, they don't engage with the thing"* (Student A).

Several students felt that they should have been better prepared for the process. In particular, they noted that the approach required an entirely different approach to learning. *"You need to purchase that approach with a different approach as well as think about it. You need to explain that material to a person who doesn't really understand. You need to guide them through several courses"* (Student A).

Overall, a majority of students preferred the flipped method of teaching over traditional lectures.

3.1.2. Students' Perspectives of Learning

One major noted benefit of the approach was the ability to view and re-engage with course content until full comprehension of the threshold subjects. *"I really enjoyed it coz I was able to pause it if I didn't know something, pause it, google it, pause it so something else, come back to it and it didn't feel like you had to stay there the whole time"* (Student I). Most students appreciated that workshops followed immediately after the associated lectures. Students indicated that the increased independence of the approach and gained a sense of empowerment from the process:

> *"The flipped classroom is very self-directed learning. You have to sit down at home, you have to watch the lecture, you have to take notes by yourself, there is no one telling you that you have to be there in class, you can do whatever you want, you don't have to go to the tutorial, you go there if you want help, if you want to push yourself and you want to learn more … but I think I really benefitted from it in the end. I really enjoyed the style and gained a lot more from, you get the materials beforehand because I think it gave me time to process it, digest it, to understand what I was looking at before I actually went in a did it" (Student M).*

A majority of the students liked the self-paced nature of the course. However, a few felt that self-paced learning disadvantaged them: *"So it forces me to invest more time than I want to, than I can"* (Student A). Two students noted that the approach does not prepare students for the schedules expected in professional practice. In particular, they noted that professionals typically do not have flexible timeframes to prepare at their own pace before they solve real-life problems. *"For quite a lot of jobs that you're going to get coming out of a degree like this, you don't wake up whenever you want and go to work"* (student J).

Nearly all students noted a need for self-responsibility and discipline in a flipped classroom: *"It takes a lot of self-control"* (Student C). While some students thought the self-responsibility was advantageous, others recognised their own immaturity meant that they were not as successful as they had hoped in the teaching approach. A few students indicated that the flipped classroom approach is generally most suitable for students with a high level of self-discipline *"I wouldn't have been able to do it when I was 18. There wouldn't have been a chance"* (Student P).

Students recognised the importance of time management in the flipped approach. A number of students found that the online lectures took too long a time to watch and the flipped approach generally took considerably more time than the traditional approach: *"At some point I was struggling to keep up with watching the videos … also a bad thing because you spent a lot more time going over it"* (Student L). A number of students mentioned the need to engage in the prescribed course material in a timely matter: *"the moment you missed one and you go to the tutorial and have no idea what's going on and then you kind of not waste that tutorial but you can't fully engage in it so you have to re-watch it that night to catch-up"* (Student O). Another student felt that the increased time investment was not reflected in improved grades.

A majority of the students liked the collaborative nature of the workshops and enjoyed the resulting group dynamics. Most also appreciated the small class-sizes and increased lecturer interaction compared to traditional classes *"I definitely feel that working with a partner or small group really helped. As soon as I hit a roadblock or something that I didn't*

understand, I could bounce ideas off [student name] and he could do the same for me" (Student D). Two students indicated that they felt responsibility to the group and thus, ensured that they were prepared to make a contribution at the workshops. One student mentioned watching and discussing the online material with a classmate.

> *"I was doing it with a very good friend of mine. We spent a lot of time we'd watch them together and we'd hit a problem and we'd both work through what [the lecturer] was trying to get towards, and the next day we'd be very confident in what we'd got" (Student D).*

However, other students mentioned that they would not like to watch the video with peers.

3.2. Discussion of Qualitative Outcomes

This study concurs with pertinent literature on student perspectives of the flipped classroom (Hanson, 2016, Nguyen et al., 2015) and lecturer behavioural factors (Blair et al., 2016). This section will discuss our findings in the context of prior research.

One rationale for adoption of flipped classrooms in tertiary settings recognises trends towards student-centred, problem based learning. This trend conforms to Vygotsky's (1978) sociocultural theory. Like the students in Nguyen *et. al*'s (2015) study, students in this cohort noted the positive aspects of working collaboratively. Nguyen et al. also commented that the group dynamics developed during the workshop caused students to study harder to ensure they can contribute to group discussions. Students indicated that the flipped approach took more time to engage with. However, the reviewability of the materials and the collaborative nature of the workshops enabled a greater understanding of the material. Working collaboratively typically generates a range of viewpoints and conforms to the sociocultural conflict theory (Doise and Mugny, 1984). Social conflict theory states that all learners' cognitive development, regardless of academic ability is benefitted by understanding conflicting views of peers. A number of students also mentioned the value of collaborative work when engaging with course materials and in workshops. This aligns with the findings of Mayer's study that suggested increased value of face-to-face interaction both with the lecturer and peers supports the apprenticeship of thinking theory (Bishop and Verleger, 2013, Lavelle et al., 2013, Doise and Mugny, 1984).

Another advantage of the flipped approach observed in this study and in other studies was that students could adjust the course content delivery rate and reviewed at the students' discretion (Blair et al., 2016, Johnson and Renner, 2012, Lavelle et al., 2013). These findings support the success and importance of student-centred learning theory (Vygotsky, 1978). However, some students in this study felt that the flipped approach took more time than other courses and indicated that undertaking too many courses at one time using the flipped approach would be arduous. Some students in this study acknowledged that although the course took a lot of time, they made efficient use of the time. Hence, they were able to decrease time in exam study.

Hanson (2016) suggested that students should be prepared for the flipped classroom approach. This study determined that students declared a desire to have the philosophy and pedagogy underpinning the flipped approach explained to them prior to engagement of the process. Negative elements of the flipped approach that emerged in this study (such as lack

of time management, self-discipline and inability to work collaboratively) were observed previously (Johnson and Renner, 2012, Lavelle et al., 2013, Mayer, 2002).

The quality of the lecturer developed materials for this cohort impacted students' perspectives of the flipped approach and was also found by Blair et al. (2016). The video materials developed for this course had a number of mathematical and formulaic errors that consumed a lot of time for some students. While students understood the difficulty in fixing the errors in on-line materials, some indicated that the errors damaged their confidence. However, others saw the mistakes as an advantage as they were forced to critically think about the materials and the differences between their ideas and those presented. Thus, the videos provided contrasting views and consolidated the ideas of the students (Doise and Mugny, 1984). The collaborative nature of the workshop sessions were very well received by students. In workshop sessions, students received immediate feedback on their level of comprehension (Choi, 2013, Maykut and Morehouse, 1994).

4.   Quantitative Methodology

A quantitative analysis was undertaken to determine whether the flipped classroom had a significant impact on academic performance. In order to determine the ongoing academic success of individuals from a flipped cohort, the performance of the students in a subsequent-year dynamics paper was considered. In particular, the grades of students that undertook the flipped classroom of the foundational paper was contrasted to the grades of students that undertook the same class in a typical, traditional delivery.

Those recruited into the mechanical or mechatronics program undertook the second-year dynamics paper in their first professional year (or second-year of study). There were 188 students enrolled in the second-year dynamics class. Prerequisite knowledge for the second-year dynamics class was predominantly covered in a first-year mechanics class of which there are two evenly divided parts: a statics section and a dynamics section. The dynamics section was taught by Dr Paul Docherty (author).

Most of the students that enrolled in the second-year dynamics course undertook a first-year mechanics class during the prior year (N=170). Eleven students used the direct entry (DE) route into the professional engineering programme, one was an international exchange student, and six had failed the second-year class in a prior attempt and were resitting the class. Since the validity of including the individuals that did not take the first year mechanics course in the year prior is statistically ambiguous, these eighteen DE, exchange, and repeating students were omitted from the statistical analysis. Figure 1 shows the recruitment pathways of the students into the second-year dynamics class.

Most students in the second-year dynamics class were successful in their first attempt of the first-year mechanics course during the previous year. The Semester 2 occurrence of the first-year mechanics course was taught using traditional lectures. Students in the summer cohort typically either failed the semester 2 occurrence (N=10) or were required to undertake remedial classes in their first year due to a lack of prerequisite high-school qualifications for first year courses. The dynamics section of the summer occurrence was taught using the flipped classroom delivery method.
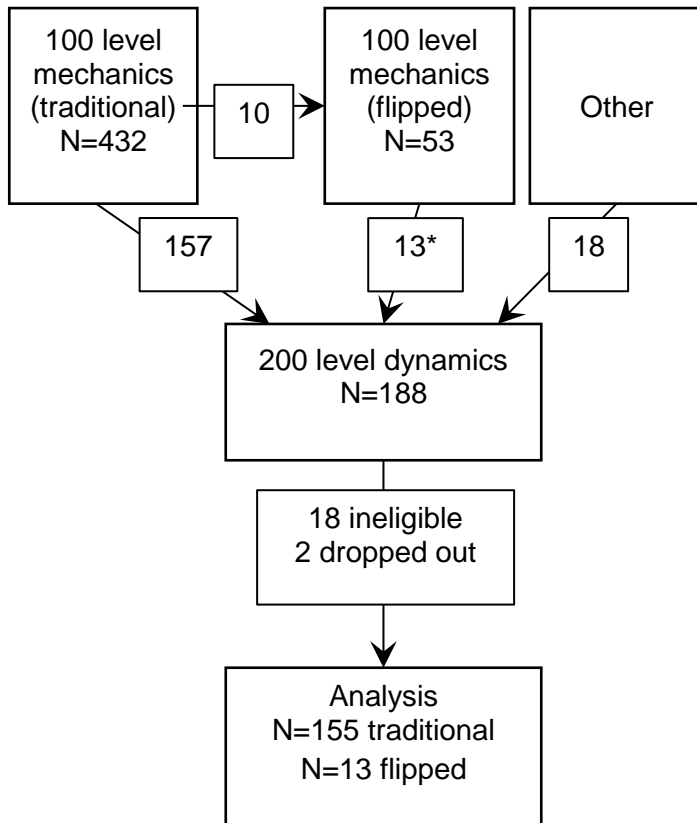
Figure 1. Pathways of students into the second-year dynamics class. (*Three of 13 were also enrolled in the traditional mechanics class)

4.1.1. Content of Second-year Dynamics Course

The second-year dynamics course taught advanced kinematics and dynamics of machine elements, vibrations and an introduction to numerical (computational) methods to evaluate differential equations. Hence, the dynamics section of the first-year mechanics class formed a foundation for successful participation in the second-year class. Formative assessment of the second year dynamics paper included weekly homework, a test, and a project. A two-hour exam formed the summative assessment. The second year dynamics class was taught using a traditional lecturing style. The lecturers of both the second year dynamics and first year mechanics papers had autonomous control over the teaching style of the classes and did not influence the outcomes of the others classes. In addition, the second-year lecturer was agnostic to the recruitment path of specific students. Hence, there was no potential for conscious or subconscious bias in grading based on whether the student underwent the flipped or traditional content delivery in the previous year. Hence, the second year lecturer was an independent assessor of the efficacy of the flipped environment for the retention of foundational dynamics concepts.

4.1.2. Analysis Methodology

The final exam marks and the aggregate marks from the second-year dynamics class were analysed and contrasted across students that undertook the flipped or traditional versions of the first year class. The traditional and flipped cohorts achieved significantly different grades

in the first year, they were poorly matched cohorts and thus violated assumptions of hypothesis testing. The average academic preparedness for those in the flipped cohort was less than the preparedness of the traditional cohort. In particular, the average intermediate GPA for those in the flipped environment was significantly lower than the average intermediate GPA from those in the traditional occurrence (Table 1). In order to achieve statistical equivalence, the cohorts were statistically normalized. First order linear regression using least squares estimation was used to determine the relationship between the second-year performance and aggregated first-year grade point averages (GPA) across both cohorts. The second-year outcomes were normalized by subtracting the expected outcome as determined by their intermediate GPA and the linear regression. This eliminated the bias introduced by the lower university preparedness of the flipped cohort. Since the data groups had uneven numbers, was unpaired and not normally distributed, the Wilcoxon rank sum and Kolmogorov-Smirnov statistical tests were used. Rank sum is a comparison of magnitude and the Kolmogorov Smirnov test measures the significance of across distribution. A significance level of 5% was used.

4.2. Quantitative Results

Overall, there were no statistically significant distinctions between the performances of the students of the flipped classroom and the traditional classroom in the follow-up class. Figure 2 shows the relationship between student outcomes from a second-year dynamic course correlated to the intermediate GPAs for the class. There was a reasonably high correlation (R=0.691) between incoming GPA and the second- year aggregated course mark of the cohort. A moderate correlation (R=0.506) was observed between the second-year dynamics exam marks and the incoming GPA. Note that there is only one regression line per analysis in Figure 2. This was necessary to allow the corrected marks to yield the appropriate distinction across the traditional and flipped cohort outcomes.
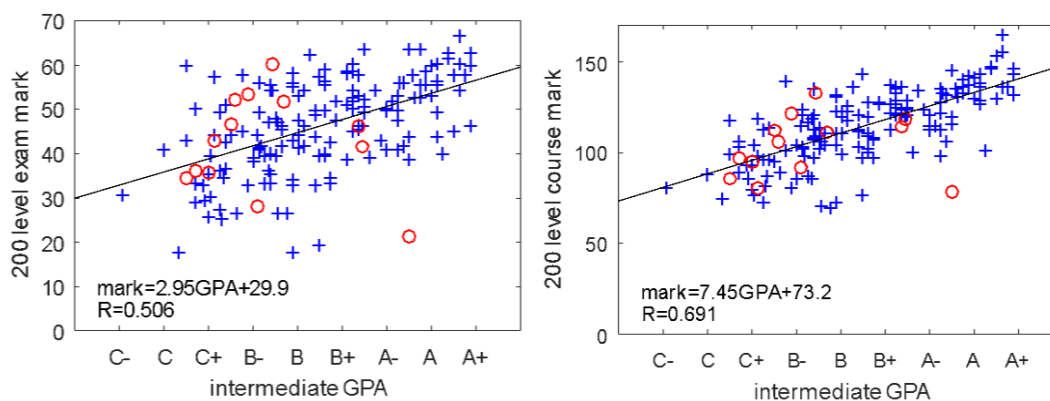
Figure 2 Regression and Pearson correlation between exam mark and intermediate GPA (left) and the correlation between aggregated course score and intermediate GPA (right). The flipped and traditional cohort are shown as 'o' and '+' symbols, respectively.

The cumulative distribution functions of the second year course outcomes for the two cohorts are shown in Figure 3. The rank sum test measures the significance of nonparametric bias across the samples, and the Kolmogorov Smirnov test determines the significance in differences in the global distribution of the curves. Table 1 summarizes the outcome statistics across the cohorts.
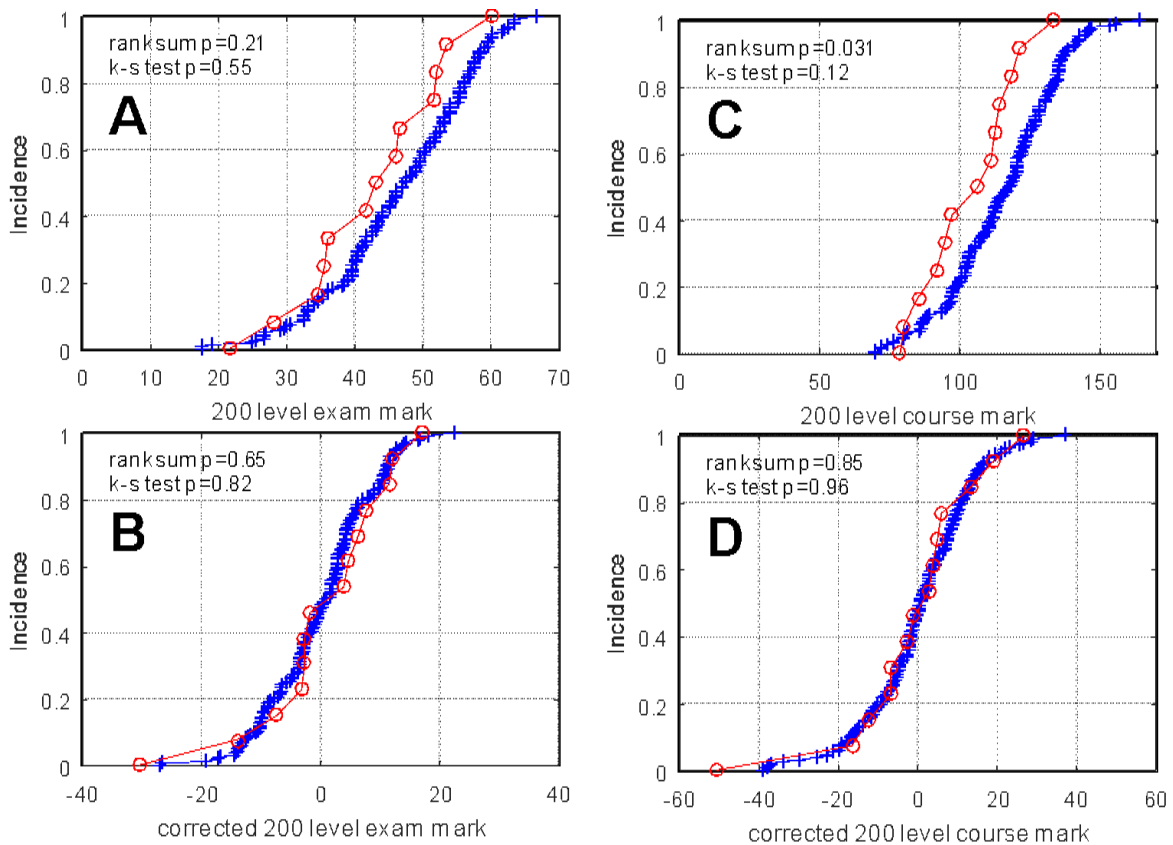
Figure 3 Cumulative distribution functions for second-year dynamics outcomes across those that undertook the first-year mechanics class using the flipped and traditional delivery. (A) uncorrected exam performance. (B) corrected exam performance. (C) uncorrected course mark. (D) corrected course mark

Table 1 shows a lack of distinction in the second year grades across the cohorts. Furthermore, the most significant distinction across cohorts was in the incoming GPA. This confirms the need for correction of grades. Overall, there were no significant changes across the cohorts when the grades were corrected. However, this does not imply the flipped classroom did not affect grades. In contrast, this outcome shows that the changes, assuming that there are changes, were undetectable in the cohorts of this study.

TABLE 1. summary statistics

	Traditional Median (Q₁, Q₃)	Flipped Median (Q₁, Q₃)	Rank sum p-value	Kolmogorov-Smirnov p-value
Intermediate GPA	5.5 (4.27, 7.00)	3.9 (3.10, 5.12)	0.012*	0.022*
Uncorrected exam mark	47.5 (39.5, 55.4)	43 (35.25, 51.6)	0.21	0.55
Corrected exam mark	0.77 (-5.90, 5.33)	0.99 (-3.26, 7.72)	0.65	0.82
Uncorrected course mark	117.5 (102, 129.6)	106 (89.9, 115.1)	0.031*	0.12
Corrected course mark	0.59 (-6.58, 9.14)	0.82 (-6.87, 5.93)	0.85	0.96

* denotes a statistically significant difference across cohorts – $p<0.05$

4.3. Discussion of Quantitative Outcomes

This analysis shows that the flipped classroom had no observable positive or negative effect on the ongoing student performance in follow-up classes. It does confirm though that the flipped approach in a summer cohort did manage to provide students with the foundational skills to succeed in the following year. Figures 3B and 3D show that the corrected grades were indistinguishable. Table 1 shows that it is impossible to declare significance in any tested metric other than the uncorrected course marks (ranksum p=0.031). However, the use of uncorrected course marks is statistically dubious. The observed differences in the CDF curves shown in Figures 3A, 3B, and 3D were too small to be statistically significant. Hence, while the teaching methodology is most likely to have had a small effect on learning and retention of dynamics, the effect was too small to capture in this present cohort.

This small effect indicates that a prospective analysis using follow-on courses as a benchmark may be difficult. Assuming a 5% contrast with a 20% variance in the performance across cohorts in follow-on performance in the follow-up course would require a study with approximately 250 students in each arm to achieve an 80% likelihood of achieving statistical significance [4]. Such numbers are infeasible for prospective analysis at mid-sized engineering faculties.

Educational research is used to inform decisions on educational policy change. Hence, it is critical that all research outcomes are reported in the academic literature. In this case, the outcome indicated that the flipped classroom provided no discernible ongoing benefit or detriment in academic performance in a follow-on course. This outcome contradicts positive outcomes previously published (O'Flaherty and Phillips, 2015a, Kerr, 2015). However, to avoid contributing to the publication bias that is known to affect educational research, studies with neutral results must be reported (Dickersin, 1990, Pigott et al., 2013, van Hilten, 2015).

The use of grades attained in a follow-on course to determine the efficacy of the flipped teaching methodology enabled a fully independent analysis. In contrast, directly measuring course marks across first-year traditional and flipped cohorts would not be researcher independent. The independence of the second-year examiner provides validity to this

analysis. Furthermore, the most important factor for determining the academic success of a foundational course is ongoing academic success of its students. Hence, this analysis directly targeted the primary focus of educational policy makers.

5. Recommendations

When considering implementation of the flipped approach, the broader, total student experience needs to be considered. Students should be offered a balanced varied programme, using a range of best practice delivery methods that have been designed to cater for a variety of needs. This study identified a number of recommendations aimed at improving students' experience in the flipped classroom. These recommendations, listed below are divided into two categories: recommendations for lecturers and recommendations for students.

Recommendations for Lecturers

•   Balance of Delivery

•   Lecturer Approach

•   Quality and Variety of Materials

•   Preparation of Students

•   Workshop Materials in Advance

•   Prepare students for methodology

Recommendations for Students

•   Student Preparedness

•   Student Engagement

•   Time Management

5.1. Recommendations for lecturers

5.1.1. Materials development and provision
Varied and balanced materials should be presented to students using a range of strategies to ensure that students remain engaged in the course. In particular, strategies could include: lecturer developed videos, use of existing materials available on the internet (such as Khan Academy), online forum discussions to enhance understanding in a collaborative way, post video quizzes and authentic collaborative problem solving and other innovative ICT tools as they emerge.

5.1.2. Lecturer attitude
A positive lecturer approach to students' potential to learn is essential. Understanding that the lecturers approach to their students learning and the material they are teaching has a huge impact on ongoing student achievement. If all students have the potential to learn then

it stands to reason that lecturer approach and attitude are the main contributing factors in students' achievement.

5.1.3. Quality of materials

Students need to have confidence that the course materials are of a high quality, succinct and engaging and without any errors. Students in this study suggested professional video editors should have been consulted during development of the course materials

5.1.4. Availability and accessibility of content

Students recommended that all workshop and video materials be available to the students well in advance so that they could better manage their time and self-paced learning. Along with this we would recommend a very clear schedule of the face-to-face workshops and with a detailed outline of content so that students are adequately prepared for each workshop.

5.1.5. Student preparation

Students need to be well prepared for the flipped approach. Most students have never experienced similar teaching approaches in the past. Hence, the process, its rationale, philosophy, advantages and inherent risks should be clearly explained to all participants prior to engagement. It should not be assumed that students have the maturity to effectively manage their time for effective self-paced learning. Opportunities for frequent student feedback on the effectiveness of the approach will also provide valuable feedback to the lecturer with regards to student readiness to learn in a flipped classroom, as well as areas that need particular attention.

5.2. Recommendations for students

5.2.1. Student preparedness

Students themselves need to be prepared for the flipped classroom. Students in this study recognised the considerable difference to other approaches, and the need to adapt. The students need to take ownership of their learning and commit themselves to taking on board strategies to succeed in the alternative flipped approach.

5.2.2. Receptivity to approach

Students' receptiveness to the alternative strategy and active engagement with peers and lecturer is critical to efficient learning in the flipped classroom. Students recognised the benefit of interacting with the lecturer and peers in the workshop and in some cases, while engaging with the videos.

5.2.3. Time management

Flipped classroom students must develop time management strategies and be self-disciplined to ensure materials are engaged with in a timely manner. Failure to engage with course material in a timely manner renders the help sessions useless. When non-attendance is ongoing and the student becomes further behind, the flipped classroom can lead to a compounding problem for the student to catch up.

6. Impacts of research

6.1. Impact on Learners

6.1.1. Retrospective
The qualitative analysis of this research indicated that the application of the flipped classroom had significant benefit in terms of student experience. However, the quantitative analysis showed that the approach had little ongoing effect on the academic performance of the students. These outcomes confirm the efficacy of the approach, in particular, for enhancing student experience.

6.1.2. Prospective
This research has shown that there is benefit in the flipped approach in the summer cohort. Hence, the approach will continue to be used in future iterations of the class. Furthermore, the recommendations of this study have led to small scale uptake of the approach in other engineering classes at the University of Canterbury. In particular, there has been a recent emergence of flipped approaches for small modules within courses. This limited uptake is partially due to the considerable time cost of producing online materials, and the time burden of learning in a flipped environment.

6.2. Impact on the teacher

6.2.1. Retrospective
The lecturer of the flipped classroom has a more in depth understanding of pedagogy as a result of facilitating the flipped classroom. Ultimately, it has provided an ongoing resource for teaching and learning that becomes increasingly efficient in terms of lecturer effort in each iteration of the class.

6.2.2. Prospective
The critical analysis of the approach made available by this research will lead to improvements in the facilitation of the course. In particular, the lecturer is more empowered to provide the students with detailed recommendations for successful engagement with the methodology.

6.3. Impact on institution

6.3.1. Retrospective
The University of Canterbury utilises best practice teaching approaches. However, the university must be cautious when implementing new approaches for teaching on a wide scale. While the academic literature almost universally indicates positive outcomes from flipped approaches the potential for publication bias remains an ongoing concern. The use of flipped approaches has been touted as a possible strategy for teaching into the engineering program and the course analysed here was one of the pilot courses of the approach.

6.3.2. Prospective
The outcomes of this research implied that the ubiquity of positive quantitative outcomes in the academic literature regarding flipped classrooms may indeed be enforced by publication

bias. However, this research also confirmed the significant benefit in terms of the student experience. Ultimately, students are very mobile, and often have the choice to attend a variety of tertiary institutions. Hence, there will be an increasing pressure on universities to provide teaching styles that are preferred by students.

6.4. Impact on Research Team

6.4.1. Retrospective

The research team was brought together for this research and was an entirely new collaboration. The skills of the team members were very distinct and cross pollenated to yield a much more comprehensive evaluation of the flipped classroom than any one researcher in the team would be able to produce. In particular, Dr Docherty was immersed in qualitative research and thus developed experience and expertise in a research methodology he has not previously been involved with. Ms Zaka and Dr Fox-Turnbull developed quantitative skills and experience working with engineering students who represented a very different culture to students the researchers have been involved with in the past.

6.4.2. Prospective

This research has provided the research team with the skills, experience, and appetite to undertake ongoing research into educational practice. Future research will involve ongoing development and improvements to the flipped classroom in the first year dynamics class. The researchers will also monitor and support the emergence of the flipped approach within the College of Engineering at the University of Canterbury. The outcomes of this study will be published and presented to disseminate the outcomes to the wider academic community.

7. Conclusions

The study aimed to investigate student experience and ongoing success after a flipped classroom approach to learning dynamics in an undergraduate engineering programme. The study determined that students were generally positive about the approach. Students' perceptions were divided into two categories. Perceptions of teaching, and perceptions of learning.

This analysis also assessed the ongoing academic performance of students from a flipped classroom in a follow-on course. The findings indicated that the performance of students who undertook the foundational class using a flipped teaching approach achieved similar academic outcomes in the follow-on course to those that undertook the foundational class using traditional methods. While ongoing academic performance is a very important metric for assessing educational success of foundational classes, the student impression and experience is also critically important to consider during the design of educational policy.

The study led to a series of recommendations for future implementations of the approach in tertiary teaching of engineering.

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